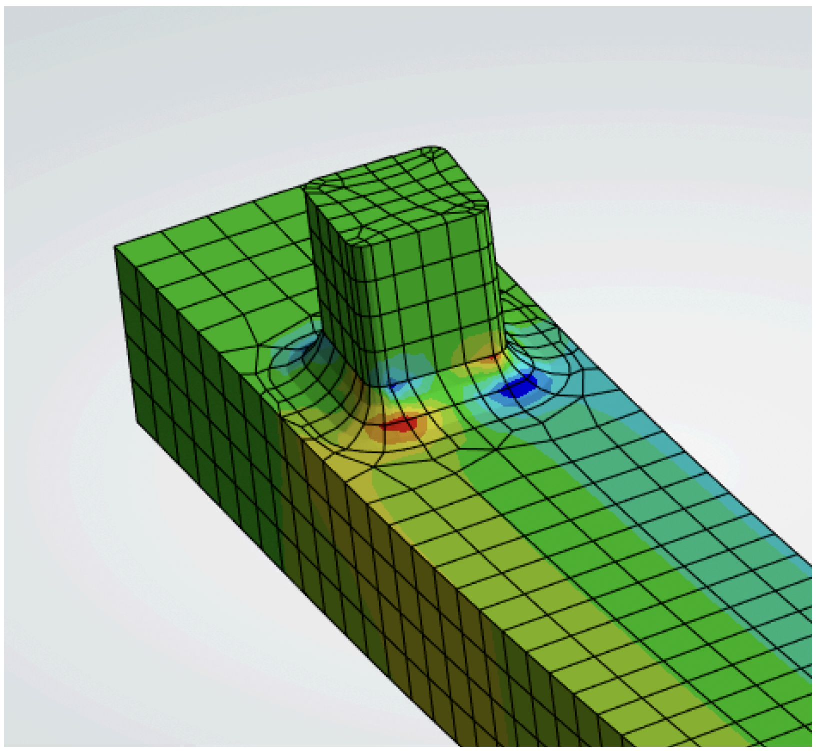
MAE 3270

Fall 2025
Wrench FEM Analysis

By:
Jason Kirkland and Justin Tsemekhin



1 Project Description

The goal of this assignment was to analyze a simple torque wrench design using both hand calculations and a finite element model on ANSYS.

2 Matlab Hand Calculations Script:

```matlab
%% Torque Wrench Hand-Calc Model
% All units: in, lbf, psi

%% Inputs ------------------------------------------------------------
M   = 600;       % max torque at drive (in-lbf)
L   = 16;        % length from drive to load point (in)
h   = 0.75;      % bar width (in)  (dimension in direction of bending)
b   = 0.5;       % bar thickness (in)
c   = 1.0;       % distance from center of drive to center of strain gauge (in)

E   = 32e6;      % Young's modulus (psi)
nu  = 0.29;      % Poisson's ratio (not used in basic hand calcs)

su        = 370e3;   % tensile strength (psi)  (use yield or UTS)
KIC       = 15e3;    % fracture toughness (psi*sqrt(in))
s_fatigue = 115e3;   % fatigue strength at 10^6 cycles (psi)

a0  = 0.04;      % assumed initial crack depth (in)
GF  = 2.1;       % strain gauge factor
bridgeType = "half"; % 'quarter', 'half', or 'full'

%% Section properties ------------------------------------------------
I = b*h^3/12;        % area moment of inertia about bending axis (in^4)
y = h/2;             % distance from neutral axis to outer fiber (in)

%% Static loading: force, deflection, stress -------------------------
F = M / L;                          % end load that gives torque M (lbf)

delta = F*L^3 / (3*E*I);            % tip deflection (in) - cantilever w/ end load

M_max = F*L;                        % max bending moment at drive (in-lbf)
sigma_max = M_max * y / I;          % max normal stress at drive (psi)

% moment and stress at gauge location (c from drive)
M_g = F*(L - c);                    % bending moment at gauge (in-lbf)
sigma_g = M_g * y / I;              % stress at gauge (psi)
eps_g = sigma_g / E;                % strain at gauge (in/in)

%% Safety factors ----------------------------------------------------
% 1) Xo Yield
n_strength = su / sigma_max;

% 2) Xk Crack growth / fracture
Y = 1.12;                           % geometry factor for edge surface crack
K = Y * sigma_max * sqrt(pi*a0);    % applied K at assumed crack (psi*sqrt(in))
n_crack = KIC / K;

% 3) Xs Fatigue (fully reversed, sigma_a = sigma_max)
sigma_a = sigma_max;
n_fatigue = s_fatigue / sigma_a;

%% Strain-gauge bridge output ----------------------------------------
switch bridgeType
    case "quarter"
        bridgeFactor = 1/4;
    case "half"
        bridgeFactor = 1/2;
    case "full"
        bridgeFactor = 1;
    otherwise
        error('bridgeType must be "quarter", "half", or "full"');


end

Vout_mV_per_V = 1000 * GF * eps_g * bridgeFactor;  % mV/V equation i looked up online

%% Display results ---------------------------------------------------
fprintf('--- Geometry & Section Properties ---\n');
fprintf('I = %.4f in^4\n', I);

fprintf('\n--- Static Response ---\n');
fprintf('End load F          = %.2f lbf\n', F);
fprintf('Tip deflection δ    = %.3f in\n', delta);
fprintf('Max stress σ_max    = %.2f ksi\n', sigma_max/1e3);

fprintf('\n--- Safety Factors ---\n');
fprintf('Yield SF Xo (su/sigma_max)        = %.2f\n', n_strength);
fprintf('Crack growth SF Xk (KIC/K)        = %.2f\n', n_crack);
fprintf('Fatigue SF Xs (s_fatigue/sigma_a) = %.2f\n', n_fatigue);

fprintf('\n--- Strain Gauge ---\n');
fprintf('Gauge strain ε_g    = %.0f microstrain\n', eps_g*1e6);
fprintf('Bridge output       = %.2f mV/V (%s-bridge)\n', Vout_mV_per_V, bridgeType);


fprintf('\n================ DESIGN SPEC CHECKS ================\n');

%% 1. Sensitivity requirement ( ≥ 1.0 mV/V )
required_mVV = 1.0;
fprintf('Output Spec:  %.2f mV/V  (Required ≥ %.2f mV/V)\n', Vout_mV_per_V,
required_mVV);

%% 2. Static yield/brittle failure (XO ≥ 4)
required_XO = 4.0;
fprintf('Strength SF:  %.2f        (Required ≥ %.1f)\n', n_strength, required_XO);

%% 3. Crack growth (XK ≥ 2)
required_XK = 2.0;
fprintf('Crack SF:     %.2f        (Required ≥ %.1f)\n', n_crack, required_XK);

%% 4. Fatigue (XS ≥ 1.5)
required_XS = 1.5;
fprintf('Fatigue SF:   %.2f        (Required ≥ %.1f)\n', n_fatigue, required_XS);

fprintf('==================================================\n\n');
```

3 Results

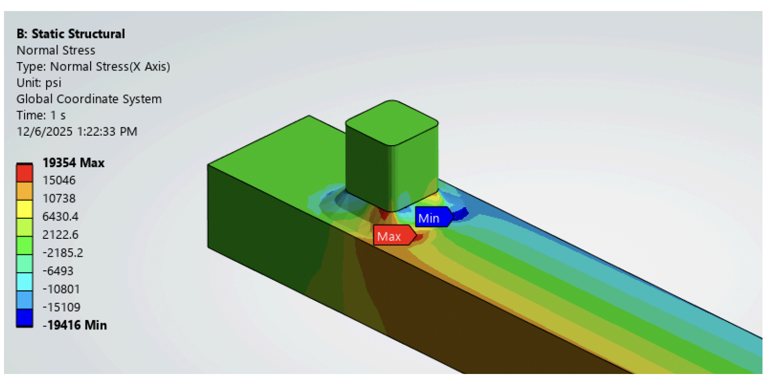
1. Results from hand calculation:

```
--- Static Response ---
End load F           = 37.50 lbf
Tip deflection δ     = 0.091 in
Max stress σ_max     = 12.80 ksi

--- Safety Factors ---
Yield SF Xo (su/sigma_max)        = 28.91
Crack growth SF Xk (KIC/K)        = 2.95
Fatigue SF Xs (s_fatigue/sigma_a) = 8.98

--- Strain Gauge ---
Gauge strain ε_g     = 375 microstrain
Bridge output        = 0.39 mV/V (half-bridge)

================ DESIGN SPEC CHECKS ================
Output Spec:  0.39 mV/V  (Required ≥ 1.00 mV/V)
Strength SF:  28.91        (Required ≥ 4.0)
Crack SF:     2.95        (Required ≥ 2.0)
Fatigue SF:   8.98        (Required ≥ 1.5)
====================================================
```

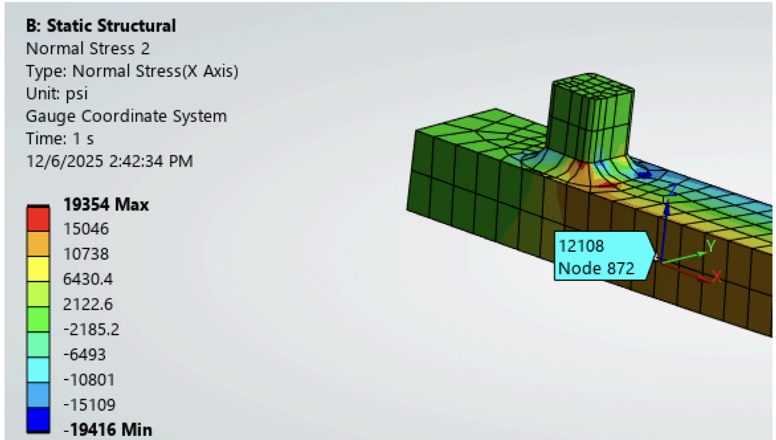
a. **Maximum normal stress at gauge:** σ_max = 12.80 ksi
b. **Strain at the gauge location:** ε_g = 375 microstrain
c. **Maximum deflection at tip:** δ = 0.091 in

2. Results from Finite Element Model (ANSYS) calculation of base design:

a. **Maximum normal stress:**

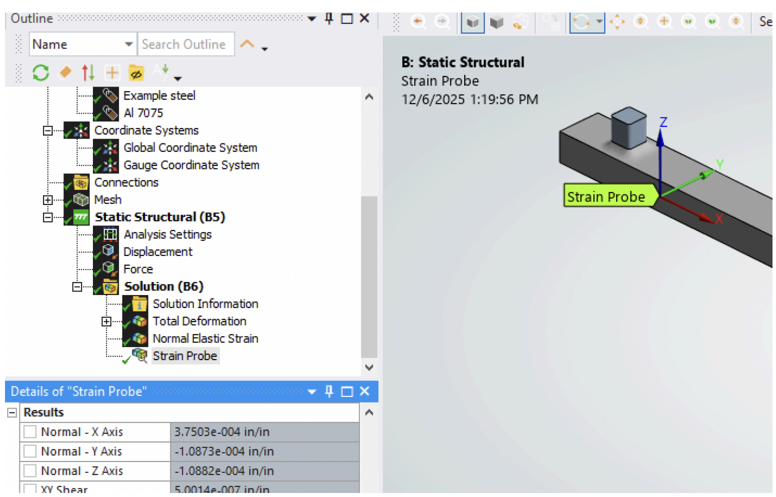


Location of Maximum and Minimum Normal Stresses: Overall Figure	
Maximum Stress: 19.35 ksi	**Minimum Stress**: -19.42 ksi



Normal Stress at Gauge: 12.1 ksi

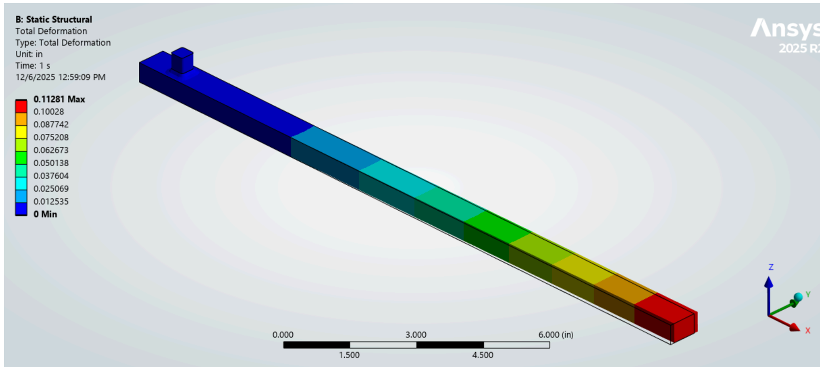
b. Strain at the strain gauge:



Maximum Normal Strain at Gauge

Normal X-axis strain at gauge: 375 microstrain

c. Maximum deflection at tip:



Maximum Tip Deflection: 0.11 in

4 Reflections

1. Based on the finite element model on Ansys, beam theory is reasonably accurate as the deformed mesh lines maintain their linear geometry. The cross section at the end of the handle shows the deformed mesh. When exaggerating the deformation, the mesh where peak deformation occurs is still shows perfect squares. Had there been noticeable bending or deformations, beam theory would not be accurate; however, in the example beam theory holds and is further supported by the proximity of the hand calculations to the FEM deflection values.

2. The FEM and hand calculated values for normal stress at the gauge location only differ by 5.5%, with the hand calculation (12.8 ksi) being higher. However, the overall maximum normal stress calculated through FEM is 19.35 ksi, significantly higher than the 12.1 ksi gauge strain predicted by the hand calculations. This largely comes from stress concentrations and can be visualized on the normal stress contour which clearly shows several areas with higher than predicted stress. These locations are the result of sharp corners and poorly designed filets, something that needs to be iterated for future designs.

3. The hand calculated displacement is 0.091 in while the FEM value is 0.11 in. This difference, with the FEM value being 21% higher, is not an alarming discrepancy. The difference may stem from the FEM model accounting for both deflection due to sheer and bending while the hand calculations only show deflection due to a bending moment applied at the edge of the handle. The sheer forces would cause the material to deflect more than what is predicted due to pure bending.

5 Our Portfolios

Jason Kirkland	https://cornell-mae-ug.github.io/Jason-Kirkland-Portfolio/
Justin Tsemekhin	https://cornell-mae-ug.github.io/fa25-portfolio-Justin-Tsemekhin/